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Energy Savings Assessment for Digital-to-Analog Converter Boxes

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Abstract

The Digital Television (DTV) Converter Box Coupon Program was administered by the U.S. government to subsidize purchases of digital-to-analog converter boxes, with up to two \$40 coupons for each eligible household. In order to qualify as Coupon Eligible Converter Boxes (CECBs), these devices had to meet a number of minimum performance specifications, including energy efficiency standards. The Energy Star Program also established voluntary energy efficiency specifications that are more stringent than the CECB requirements. In this study, we measured the power and energy consumptions for a sample of 12 CECBs (including 6 Energy Star labeled models) in-use in homes and estimated aggregate energy savings produced by the energy efficiency policies. Based on the 35 million coupons redeemed through the end of the program, our analysis indicates that between 2,500 and 3,700 GWh per year are saved as a result of the energy efficiency policies implemented on digital-to-analog converter boxes. The energy savings generated are equivalent to the annual electricity use of 280,000 average US homes.

Keywords: set-top boxes; electricity savings; standby power

1 Introduction

On June 12, 2009, the United States switched from analog to digital over-the-air television broadcasting for all full-power stations. The US has about 110 million households with TVs (Nielsen, 2009) and was the largest market to have made the transition. Many consumers had not yet purchased digital televisions that were able to receive the digital signals. In February 2008, at least 13 million households in the United States had analog televisions that could receive only analog broadcast signals (Nielsen, 2008). There was widespread concern that these households would not be prepared for the transition and would be unable to receive a television signal.

In order to facilitate the Digital Television (DTV) transition, the Digital Television Transition and Public Safety Act of 2005 authorized the National Telecommunications and Information Administration (NTIA) to establish a DTV Converter Box Coupon Program (Federal Register, 2007). Eligible households could receive up to two \$40-coupons, between January 1, 2008 and July 31, 2009 (expiring 90 days after they were issued), toward Digital-to-Analog converter box (DTA) purchases. These \$40-coupons covered most of the converter box cost, which was typically \$50-60.¹ Through December 2009, about 35 million coupons were redeemed from the NTIA coupon program (NTIA, 2009).

¹ The NTIA defined the “Coupon Eligible Converter Box” (CECB) DTA as a “Stand-alone device that does not contain features or functions except those necessary to enable a consumer to convert any channel broadcast in the digital television service into a format that the consumer can display on

In 2004, there was concern regarding the potential energy impacts of DTAs (Meier, 2004). These boxes were expected to continuously draw as much as 20 watts, or 180 kWh/year. For example, ten million boxes, each drawing 15 watts, would add 1300 GWh per year to national electricity consumption. Several studies described at the 2004 and 2007 International Energy Agency (IEA) workshops indicated that the boxes could be manufactured to consume much less energy at only a modest increase in cost (Dale, 2004). The California Energy Commission therefore initiated hearings to establish minimum efficiency standards for DTAs. Other states were poised to enact similar standards.

Negotiations among the major stakeholders resulted in an agreement that proposed mandatory regulations would be withdrawn but that coupon-eligible DTAs must also meet certain energy efficiency requirements. Separate from the NTIA coupon program, the Energy Star program established voluntary energy efficiency specifications that were more stringent. Energy Star compliant DTAs were also required to comply with all NTIA coupon program specifications.

television receivers designed to receive and display signals only in the analog television service, but may also include a remote control device. (NTIA 2007)”

Figure 1. Digital-to-Analog Converter Box



Few, if any, energy-using products have entered widespread use as rapidly as the DTA. The increase in electricity consumption from a new product is also unprecedented. About 79% of countries around the world have not started the DTV transition, and 42% may do so in the near future (Tarr, 2009). It is therefore worthwhile to document the DTA's energy impacts and estimate the energy savings resulting from the efficiency requirements established through NTIA and Energy Star. This information will also help demand forecasters as these units are gradually removed and replaced with digital televisions. To estimate these impacts, our study combines field measurements with NTIA data.

2 Energy Efficiency Policies

2.1 Origins of DTA Performance Levels

The rising energy use of set-top boxes (STBs) was first noted in 1997 (Harrison, 1997) and began to appear regularly in studies of energy use in homes thereafter. In 2001, STBs were recognized as an important contributor to standby power consumption in California and as an important target for energy-saving policies. The IEA convened a workshop in 2004 to address energy use of STBs. By

that time, the first digital transitions of over-the-air television were underway in Berlin and Italy. Participants in the workshop recognized that DTAs and “complex” set-top boxes were fundamentally different devices and that each required unique energy efficiency strategies. Furthermore, huge numbers of DTAs would soon appear in the marketplace and energy guidelines were critical. The IEA workshop participants recommended maximum power levels for DTAs. Within months, these levels (or slight variants) were adopted by many government agencies and organizations, including Energy Star, the European Code of Conduct, and the Australian Greenhouse Office.

2.2 Performance Levels Established by NTIA and Energy Star

In the US, energy efficiency standards were set for over-the-air DTAs at the national level through the implementation of the NTIA coupon program. All coupon-eligible DTAs had to comply with the following energy efficiency standards set by NTIA (2007):

- Sleep state power consumption of no more than 2 W, measured in accordance with industry standard CEA-2013-A².
- Capability to switch from On state to Sleep state (or auto-power down) after 4 h of user inactivity.

The voluntary standards implemented by the Energy Star program required that DTAs meet stricter energy efficiency standards in addition to complying with

² Consumer Electronics Association (CEA). ANSI CEA-2013-A “Digital Set Top Box Background Power Consumption”, July 2007.

the NTIA coupon program. In essence, the additional standards required are (EPA, 2007):

- On mode power consumption of no more than 8 W, measured using Section 6 of CEA-2022³, and Sleep mode power consumption of no more than 1 W using Annex A of CEA-2013-A.
- DTAs “may come out of Sleep Mode in order to scan for program and system information or private data. When doing so, DTAs may exceed the 1 W Sleep Mode requirement for no longer than one hour in an eight-hour period.”

The California Energy Commission (CEC) had also adopted its own energy efficiency standards for DTAs. The CEC required converter boxes to have On and Sleep mode power consumption of no more than 8 W and 1 W, respectively, but had no requirement on the auto-power down feature, unlike the NTIA coupon program (CEC, 2007a). In October 2007, the CEC repealed its existing efficiency standard on DTAs, because the NTIA coupon program was believed to generate an equivalent or greater level of energy efficiency (CEC, 2007b).

2.3 Digital Cable Transition

Households served by cable television are also undergoing a digital transition. For example, Comcast Cable is upgrading their Expanded Basic Cable, which includes 30-50 channels, to digital signals (Comcast, 2009a), and the upgrade is expected to last through the year 2010 (Comcast, 2009b). To continue viewing

³ Consumer Electronics Association (CEA). ANSI CEA-2022 “Digital Set Top Box Active Power Consumption Measurement”, August 2007.

these channels, service providers give customers with analog televisions the option to obtain a digital transport adapter or digital cable box (Comcast 2009b). The digital transport adapter has the primary function of converting digital cable signals to analog, whereas a digital cable box carries more functions such as on demand and pay-per-view. Alternatively, customers can replace their analog televisions with new, digital units at their own cost.

NTIA did not offer coupons for purchasing cable DTAs because it was assumed that the cable service providers would provide them for free (which they did). By being outside of the NTIA coupon program, cable DTAs were not covered by performance requirements. In addition, this meant that cable DTAs were not covered by the coupon reporting requirements. For this reason, our analysis excludes cable DTAs; however, we report measurements on two units for comparison.

3 Methodology

3.1 General

The goal of this study is to assess the effectiveness of energy efficiency standards applied to coupon-eligible DTAs, through power and energy measurements in home settings. The power consumption data collected are applied to an assumed usage pattern to generate an average annual energy consumption. This “policy case” annual energy consumption is then subtracted from a “reference case” annual energy consumption to estimate energy savings generated by the energy efficiency policies. The “reference case” annual energy consumption is computed based on a baseline power consumption, which is expected if the energy

efficiency policies did not exist; details of how this baseline power consumption was obtained are discussed in the following sections. Finally, the average energy savings per converter box is multiplied by the number of coupon-eligible DTAs sold in order to estimate aggregate energy savings.

To collect data on power and energy consumption, a sample of 12 coupon-eligible DTAs (6 of which are Energy Star labeled) were selected for 24 h continuous measurements with the Power Line Meter (PLM)⁴. Most of the DTAs metered were available in the market in May 2009, weeks before the DTV transition. The sample size is relatively small but well represents the population of DTAs for a number of reasons. Because all coupon-eligible DTAs are required to comply with NTIA specifications, they have limited and consistent functionality. This is unlike products such as digital televisions where a wide range of models and different features are available. In addition, market research information up to the first quarter of 2009 indicated that 13 brands of coupon-eligible DTAs accounted for 90% of total sales (DTC, 2009). Lastly, large numbers of coupon-eligible DTAs were sold in big national retail stores, such as Walmart, Target, Radio Shack, and Best Buy, and each of these stores only carried a couple models at a time. All these factors suggest that DTA functionality and model variety are more homogenous than other electronic products, which supports the selected sample size.

⁴ The Power Line Meter, model PLM1-LP, is a single phase power multi-meter manufactured by Electronic Product Design, Inc. in Oregon, USA. Power is supplied to the load via a permanent power cord exiting the rear panel and a 4 amp, 120 volt outlet on the front panel. Connection to a computer for data recording is through a serial connector.

3.2 Measurements

Different operating modes of the converter boxes were tested and corresponding power consumptions measured during the course of the metering. Since we observed that recording frequencies of the PLM were not biased by power measurements, we were able to take the average of power measurements in each operating mode during data processing. The DTAs were also tested for their capability to auto-power down after the default of 4 h, a feature required by both the NTIA coupon program and Energy Star label.

3.3 Baseline Power Consumption

A baseline power consumption is used as the reference case in order to estimate energy savings produced by the energy efficiency standards. Since DTAs were new to the US market before the DTV transition, a commercial unit was not available for assessing the baseline before the policies took place. However, when the CEC was assessing the feasibility of their version of energy efficiency standards, Zoran, a manufacturer of electronic chipsets and consumer products, presented an estimate of probable power requirements for simple converter boxes. Power input for a list of components including tuner, receiver/demodulator, decoding, memory, associated analog circuits, and power supply were listed for the Zoran construct, with an estimated range of total power consumption of 11.7-14.2 W (Energy Solutions et al., 2006). Since this power consumption represents what the industry believed was feasible without policy intervention, it serves as a reasonable baseline. For this study, we use the range of 12-14 W as the baseline power consumption for the purpose of estimating energy savings.

3.4 Converter Box Sales

Converter box sales data are used to estimate aggregate energy savings produced by the energy efficiency policies. NTIA keeps track of coupon redemption statistics by state and zip code, and thus sales data for coupon-redeemed DTAs are readily available. Every March, the Energy Star program requests that partners of Energy Star labeled products supply shipment data for the previous calendar year; however, only shipment data, but not sales data, are reported. We intended to assess the effectiveness of the NTIA coupon program and Energy Star program separately, but because of the lack of reliable sales data on Energy Star labeled units, we determined it is more appropriate to estimate energy savings generated by the NTIA coupon program as a whole.

4 Results

4.1 Digital-to-Analog Converter Boxes

4.1.1 Technical Considerations

The 12 coupon-eligible DTAs measured in this study are listed in Table 1, together with information on the auto-power down feature, activity during Sleep mode, average On and Sleep mode power consumptions, and observed compliance with the NTIA coupon program and/or Energy Star. For Energy Star labeled products, manufacturers are required to test their converter boxes under specific test procedures for three different input signals and report the highest power values. Table 1 presents these reported power consumptions, for comparison with the measured values in home settings.

Among the 12 measured DTAs, DTA#12 is not capable of auto-powering down after the default of 4 h, even though the manufacturer claims the box has this function. All converter boxes measured have multiple time options for auto-power down, including mixed combinations of 1-8 and 12 h. DTA#10 was found to wake up for about 10 minutes for every 4 h in Sleep mode. The power consumption during this 10-minute period is slightly lower than the On mode power consumption (approximately 6 W rather than 7.1 W). All other converter boxes measured have relatively stable power consumption when in a particular power mode. A continuous measurement plot for DTA#2 is shown in Figure 2. The NTIA Sleep mode (2 W) and Energy Star On and Sleep mode (8 W and 1 W) requirements and the baseline power consumption of 12 to 14 W are depicted in the figure.

All measured DTAs have relatively low power consumptions. The average On and Sleep mode power for Energy Star labeled products are 5.4 and 0.6, respectively, whereas for products that are not Energy Star labeled, they are 7.6 and 0.9, respectively. It is interesting to note that the difference in power consumptions between the two groups of products is relatively small. The products that are not Energy Star labeled achieved relatively low On mode power consumption, even though no requirement was imposed for On mode power under the NTIA coupon program. As shown in Table 1, DTA #9 and 11 have measured values that are below the Energy Star requirements of 8 W and 1 W for On and Sleep, respectively, but they are not Energy Star labeled products.

4.1.2 Cost Considerations

When the Title 20 efficiency standard for DTAs was first adopted in California, manufacturers resisted the standard and lobbied for its repeal, perhaps due to concerns that the levels were technically difficult to achieve (Energy Solutions et al., 2006). And even if the standard was technically feasible, cost of manufacture was another concern, particularly for these simple converter boxes where profit margins were expected to be low.

By observing the power consumptions and retail prices of the 12 metered DTAs in Table 1, we note that all converter boxes cost between \$44 and \$60 and there is no observable price difference between the more energy efficient units and the rest. Furthermore, the price distributions between the Energy Star and non-Energy Star units are similar and Energy Star labeled products do not cost more. Although a baseline cost is not available to derive the exact cost of the energy efficiency policies at the converter box level, our data suggest that there is no correlation between price and power consumption among the different coupon-eligible DTAs.

4.2 Cable Converter Boxes

Although not the focus of this paper, as part of the study, we performed measurements on two cable converter boxes distributed to customers by Comcast Cable; details of the metering data are summarized in Table 2. Cable converter box #1 is an Energy Star labeled digital transport adapter and has relatively low On mode power consumption, namely 3.9 W. With the On mode as the only power mode, the box cannot be switched off unless it is unplugged from the power source. Cable

converter box #2 also does not have an auto-power down option and consumes about 10 W of power during On mode.

Table 1. Digital-to-Analog Converter Boxes (DTAs) Metering Data

Products	Retail Price	Auto-Power Down after 4 hrs?	Wake Up During Sleep?	On Mode (W)	Sleep Mode (W)	Observed Compliance		E* Reported On (W)	E* Reported Sleep (W)
						Energy Star	NTIA		
Energy Star (E*) DTAs									
1	\$60	Yes	No	4.2	0.7	√	√	7.2	0.84
2	\$50	Yes	No	6.3	0.8	√	√	5.96	0.57
3	\$50	Yes	No	3.8	0.5	√	√	3.9	0.6
4	\$60	Yes	No	5.7	0.6	√	√	6.0	0.7
5	\$60	Yes	No	6.5	0.5	√	√	6.71	0.6
6	\$50	Yes	No	5.8	0.8	√	√	N/A ^a	N/A ^a
Average				5.4	0.6				
Non-Energy Star DTAs									
7	\$50	Yes	No	7.9	1.5		√		
8	\$50	Yes	No	10.3	0.2		√		
9	\$44	Yes	No	4.5	0.8		√		
10	\$60	Yes	Yes ^b	7.1	1.8		^c		
11	\$50	Yes	No	7.2	0.4		√		
12	\$60	No ^d	No	8.8 ^e	0.6 ^e		^f		
Average				7.6	0.9				
Overall Average				6.5	0.8				

^a Although product is Energy Star labeled and meets Energy Star requirements, it is not listed in the published Energy Star digital-to-analog converter box list.

^b Auto-power down after approximately 4 h and 10 minutes. Converter box wakes up for approximately 10 minutes for every 4 h in Sleep Mode. During this 10-minute period, power consumption is approximately 6 W.

^c We did not observe compliance because DTA#10 woke up for about 10 minutes for every 4 h in Sleep mode, and the power consumption during this 10-minute period exceeded the 2-W NTIA Sleep mode requirement. However, NTIA may have a different interpretation of coupon program compliance in this special case.

^d Converter box was not capable of auto-powering down when configured with any of its available sleep time settings. This was observed for two units of the same model purchased from the same retail store.

^e For Converter Box #12, two boxes of the same model were metered, and their On and Sleep mode power consumptions were 8.8 W and 0.4 W, respectively, for the first box, and 8.8 W and 0.8 W, respectively, for the second box. The On and Sleep mode power consumptions listed are the average of these two sets of measured power values.

^f We did not observe compliance because DTA#12 could not auto-power down for 2 of the same models tested; however, we are unsure if this condition is common among the entire product line or only this product batch.

Figure 2. DTA#2 24-hr Measurements

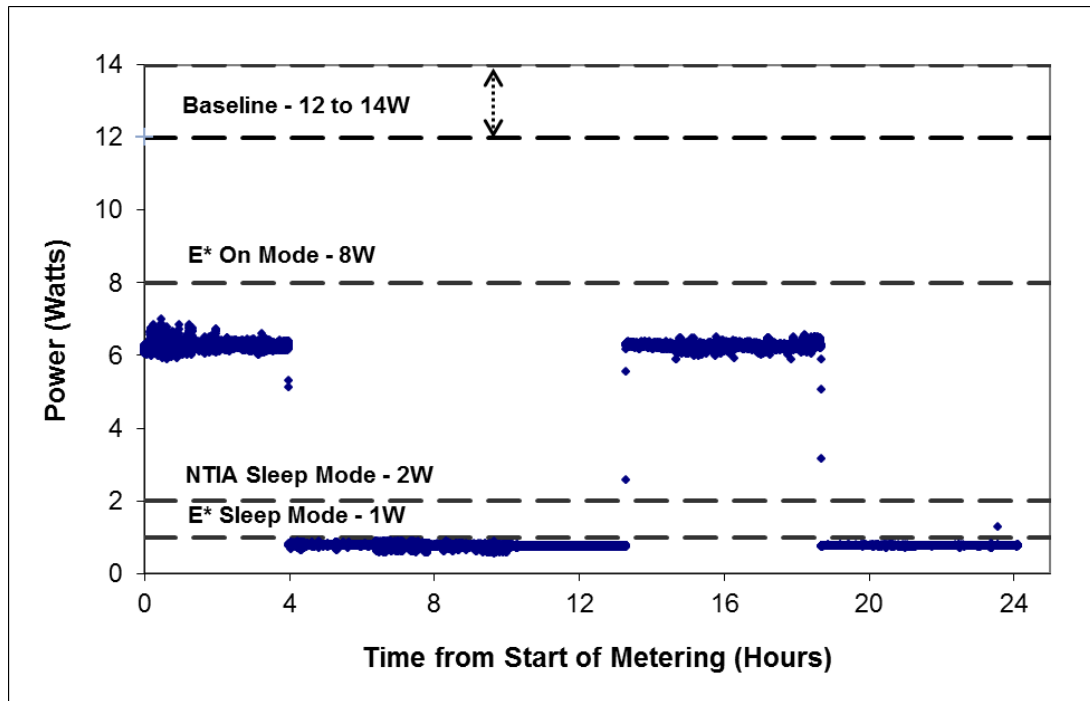


Table 2. Cable Converter Boxes - Metering Data

Products	Type	Auto-Power Down?	Wake up during Sleep?	On Mode (W)	Sleep Mode (W)
1	Digital Transport Adaptor	No	N/A	3.9	N/A
2	Cable Converter Box	No	N/A	10	N/A

5 Analysis

The following analysis estimates energy savings generated by the NTIA coupon program, based on measured converter box power consumptions, baseline power consumption, and an assumed usage pattern. Because of the small sample size of DTAs measured and the short metering period, a representative usage pattern cannot be derived from the collected data. Instead, the usage pattern used to forecast energy savings for the Energy Star DTA program is assumed.

Table 3 summarizes the usage pattern assumptions used in the analysis and energy savings results. The baseline power consumption of 12-14 W results in an annual energy consumption of 105-123 kWh per year per converter box, given that the converter box is powered on at all times. No Sleep mode is assumed for this reference case, because the Sleep mode and auto-power down feature are unlikely to be incorporated into the converter box design without policy intervention.

As indicated in Table 1, the average On and Sleep mode power consumptions for the DTAs measured are 6.5 W and 0.8 W, respectively. These power consumptions are applied to the usage pattern obtained from the Energy Star DTA program to estimate an average annual energy consumption per converter box. As a first step, average annual energy consumptions are computed from the measured power consumptions for 4 general modes of operation (Table 3):

- 1) Auto-power down is enabled and user turns down DTA after TV viewing;
- 2) Auto-power down is enabled and user leaves DTA on after TV viewing;
- 3) Auto-power down is disabled and user turns down DTA after TV viewing;
- 4) Auto-power down is disabled and user leaves DTA on after TV viewing.

For these computations, the following parameters are assumed (Table 3):

- DTA is in active mode for 5 h a day, while the TV is operating.

- DTA is in “power-down delay” mode for 8 h a day, to account for the DTA turning on more than once a day and needing to wait to power down each time.
- 100% of DTAs are turned on per day.
- DTAs are in use 351 days in a year.

In the second step, the annual energy consumptions previously computed for these 4 operation modes are weighted to obtain the overall average annual energy consumption per converter box, based on the following assumptions (Table 3):

- Auto-power down enabling rate of 80%.
- 50% of all DTAs are left on 24 h a day.

The overall average annual energy consumption results in about 30 kWh per year per coupon-eligible DTA, which translates into energy savings of about 80-100 kWh per year, compared to the baseline energy consumption of 110-120 kWh per year (Table 3). Based on the NTIA coupon redemption statistics of about 35 million (NTIA, 2009), the aggregate energy savings are estimated to be 2,700-3,300 GWh per year.

5.1 Scenario Analysis

Because the usage pattern used in the analysis is a best estimate based on previously collected data on televisions, we performed a scenario analysis for two additional usage patterns, by adjusting the time spent in active mode and power-down delay used in the original scenario. As shown in Table 3, for the low usage pattern scenario, the time spent in active mode is adjusted from 5 h, in the original best estimate, to 2 h, and the power-down delay time changed from 8 h to 4 h. This combination of changes is aimed to capture users who typically spend less time

using the TV and DTA and in turn results in a shorter power-down delay time. On the other hand, the high usage pattern scenario assumes a longer TV viewing time, from 5 h in the original estimate to 8 h. Power-delay time is also increased to 10 h from 8 h in the original estimate, as the default power-down time of 4 h may be interrupted due to more frequent operation of the TV, thus prolonging the overall power-down delay time.

Using the same method of analysis as for the original usage pattern, the scenario analysis results in energy savings of 3,000 to 3,700 and 2,500 to 3,100 GWh per year, for the low and high usage pattern scenarios, respectively, compared to energy savings of 2,700 to 3,300 GWh per year for the original usage pattern. Intuitively, the high usage pattern scenario should generate higher savings. However, in our analysis, because the baseline energy consumption is always held constant at 110 – 120 kWh per year (based on the constant baseline power consumption of 12-14 W), the low usage pattern scenario actually results in higher energy savings.

Table 3. Energy Savings Estimate for NTIA Coupon Program

	Usage Scenarios			
	Best Estimate	Low	High	
1. Baseline				
Total Redeemed Coupons	34,879,122	34,879,122	34,879,122	^a
Average On mode(W)				
Lower Limit	12	12	12	^b
Upper Limit	14	14	14	^b
Average Sleep mode (W)	-	-	-	
Average Annual Energy, per converter box (kWh/yr)				
Baseline - Lower Limit of 12 W	105	105	105	^b
Baseline - Upper Limit of 14 W	123	123	123	^b
2. Usage Pattern Assumptions				
% of units turned on per day	100%	100%	100%	^c
# days in use per year	351	351	351	^c
Enabling Rate	80%	80%	80%	^c
% of units left on 24 hrs/day	50%	50%	50%	^c
Duty cycle -				
Active mode, while TV set operating (hrs/day)	5	2	8	^c
Active mode, powering down delay time (hrs/day)	8	4	10	^c
# of hours in On mode per day	13	6	18	^c
# of hours in Sleep mode per day	11	18	6	^c
3. Results				
DTA Average On mode (W)	6.5	6.5	6.5	^d
DTA Average Sleep mode (W)	0.8	0.8	0.8	^d
General Modes				
Average kWh/yr, enabled and turned off manually	17	11	23	^e
Average kWh/yr, enabled and left on	33	19	43	^e
Average kWh/yr, disabled and turned off manually	17	11	23	^e
Average kWh/yr, disabled and left on	57	57	57	^f
Average Annual Energy, per converter box (kWh/yr)	27	18	34	^g
Energy Savings per unit, Compared to Baseline (kWh/yr)				
Baseline - Lower Limit of 12 W	78	87	71	
Baseline - Upper Limit of 14 W	96	105	89	
Total Energy Savings, for all redeemed coupons (GWh/yr)				
Baseline - Lower Limit of 12 W	2,700	3,000	2,500	
Baseline - Upper Limit of 14 W	3,300	3,700	3,100	

^a Obtained from NTIA coupon program statistics, through end of program (NTIA 2009).

^b Baseline DTA converter box power consumption of 12-14 W obtained from (Energy Solutions et al., 2006).
- For baseline annual energy consumption, assume no Sleep mode is available for converter box, and that converter box is on 24 h/d, 365 days/yr.

^c EPA Energy Star usage pattern assumptions. For Duty Cycle, only the best estimate is obtained from Energy Star; low and high usage scenarios are based on varying time spent in active mode and power-delay time of the best estimate.

^d See Table 1.

^e Computed based on measured On and Sleep Mode power, duty cycle assumptions, and the assumptions that 100% of units are turned on per day and units are in use for 351 days per year (rest of the year strictly in Sleep Mode).

^f Under this mode, DTA is in On Mode throughout the year; also assume 100% of units turned on per day.

^g Distribution of energy consumptions between the 4 general modes, based on Energy Star usage pattern assumptions of 80% enabling rate & 50% of units left on 24 hrs/d (the other 50% are turned off manually).

6 Conclusions

Among electronic products, DTAs are unique in that energy efficiency standards were implemented as part of a government assistance program before they became available in the US market. Based on our measurements of 12 DTAs that qualify for the NTIA coupon program, we found that the energy efficiency standards implemented on DTAs resulted in lower per-unit power consumption when compared to the baseline power consumption of 12-14 W. The high redemption rate of 35 million coupons indicates that a significant portion of DTAs was purchased through the coupon program. The program was very visible and well received by the public, as documented by a recent Consumer Electronics Association survey (CEA) (2009), which resulted in high program participation.

Based on our analysis, the NTIA program is saving roughly 2,500 to 3,700 GWh per year, which equals the annual output of about one 500-MW baseload power plant, or the annual electricity use of 280,000 average US homes⁵. Conveniently, this electricity savings is equivalent to about one Rosenfeld.⁶

⁵ Based on Energy Information Administration (EIA) statistics

<http://tonto.eia.doe.gov/ask/electricity_faqs.asp>, updated February 6, 2009, that the average monthly residential electricity consumption was 936 kWh in 2007.

⁶ In honor of Dr. Arthur Rosenfeld, who has made significant contributions to the field of energy efficiency and has used a 500-MW power plant operating 5000 h per year as his standard avoided plant due to energy efficiency measures, one Rosenfeld unit is defined to be an average coal plant capacity of 500 MW, with a capacity factor of 70% and system wide transmission and distribution (T&D) losses of 7%, or the annual electricity delivered of about 3,000 GWh per year (Kooimey et al. 2010).

The US and several other countries have completed their transition from analog to digital television broadcasting. Compared to the US, countries that have yet to go through the transition are likely to have less dramatic uptake of DTAs because they will have longer to replace old analog TVs with DTVs. Nevertheless, big opportunities still exist for lowering the energy consumption of converter boxes in these new markets. The broadcasting technology and equipment required for signal conversion may vary between countries, but the energy efficiency standards established in the US and other countries for DTAs could serve as examples for the new markets.

In the US, energy consumption of DTAs will likely decline as consumers replace their analog TVs with DTVs gradually, although some non-coupon-eligible boxes with additional features such as premium channels and DVR may remain in service longer, and consumers may also shift the use of DTAs to their secondary TVs. Potential future work on the energy use of TVs includes: Estimating the energy consumption associated with the retirement of DTAs, assessing the effect of the increased market penetration of DTVs, and the energy impact of new 3-D TVs that have just begun penetrating the market.

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